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ASSESSMENT OF THE VARIABILITY OF YIELD OF MAIZE IN LILONGWE DISTRICT IN RELATION TO CLIMATE CHANGE USING DSSAT MODEL

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Abstract

Malawi is vulnerable to climate change and variability because agriculture production is rain-fed and dominated by smallholder farmers. Variability in rainfall affects crop productivity and calls for the need to generate information on seasonal rainfall and temperature characteristics to guide in decision making on adaptation strategies. In this study, analysis of historical data sets of daily rainfall and temperature was done to generate information on seasonal rainfall characteristics that would be used to understand climate variability and opportunities for adaptation of maize based cropping systems.

DSSAT model was used to run the crop simulations for the cropping season of 1996/1997 to 2007/2008 for growth, development and yields of hybrid Maize at Chitedze Agriculture Research Station, and to assess which agronomic management practices can help adapt to climate variability. The DSSAT model was used to provide information concerning management options such as the timing of planting, specifically the impact on the yield with reference to different planting dates at Chitedze Agricultural Research Station.

The results show that planting maize early December (15th December) increase yield other than late and early November (30th November and 15th November respectively), late December, and late and early January for Chitedze, supported by the Index of Agreement of 0.861 (d-stat) which signifies the closeness of the relationship between the observed and the simulated yield, and the efficiency of DSSAT model to simulate yield with little root mean square of error (220.69 kg/ha), R2=0.770, mean difference of -99.61 kg/ha. The mean observed maize yield was 1350 kg/ha and the mean simulated being 1250 kg/ha through regression analysis were positively correlated, R2=0.77.

Keywords: Climate variability, DSSAT model, crop modeling, maize, planting date

Introduction

Climate of Malawi

The climate of Malawi is sub-tropical, which is relatively dry and strongly seasonal. The warm-wet season stretches from November to April, during which 95% of the annual precipitation takes place. Rainfall is unimodal with yearly average varying from 725mm to 2,500mm with Lilongwe having an average of 900mm (Department of Meteorological Services, 2009).

Crop production in Malawi

Agricultural production is under rain-fed conditions. Crops grown includes cereals (maize, rice, millet, and sorghum), legumes (soybean, common beans, and pigeon peas, cowpeas, and Bambara nuts), tobacco, cassava and sweet potatoes. As in other countries in southern Africa, cropping systems are dominated by

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maize as the main staple food (Malawi Integrated Household Survey, 2005).

Maize production in Malawi amounted to 3,445,000 tonnes in 2007, (MOAFs 2007). The domestic production has fluctuated widely from one year to the next over the recent 16 years, with the average standing somewhere between 1 million and 2.5 million tonnes. Production below 1.5 million tonnes indicates a famine, which occurs every two or three years.

Soil moisture is one of the determinants to plant growth and development. There is a clear distinction between the rainy and dry seasons. Maize is grown in the rainy season. It is also cultivated during the dry season at small scale in areas where irrigation facilities are available. Frequent droughts seriously destabilize maize production, failing to meet the food needs of the population.

Climate and agricultural production

Climate is one of the important factors that affect agricultural production. Some of the climate variables that affect plant growth and development are light, rainfall and temperature. Plants require optimum levels of each of the climate variables for various plant physiological processes. Climate hazards caused by climate change and extreme weather events have negative impacts on agricultural production. Some of these climate hazards are droughts, excessive rainfall, high temperatures, floods, unpredictable onset of planting rains, early cessation of rainfall, (Malawi National Adaptation Programmes of Action 2006). Erratic rains results into acute crop failure that results into food insecurity and malnutrition due to low food production.

Droughts and floods, in particular adversely affect food, water, health, energy and the sustainable livelihoods with about 65% of the population living below the poverty line that most of the times do not have capacity to cope with, or adapt to the extreme impacts of climate change events.

The effects of climate variability have significant impacts on agricultural production and this is important for countries like Malawi where agriculture is predominantly rain-fed. There is need therefore to identify cropping systems for adapting to climate change and variability (Malawi National Adaptation Programmes of Action 2006).

Climate change has vast effects on crop production. Water in all its forms plays a vital role in the growth of plants and the production of all crops (Ayoade, 2004). It provides the medium by which food and nutrients are carried through the plant. Ezedimma (1986) reported that water is the main constituents of the physiological plant tissue and a reagent in photosynthesis. Water is required for all metabolic reactions in plant. If the climatic conditions are not conducive plant growth is affected hence resulting into low crop production since germination is affected where rainfall is erratic. Intense temperatures also affect metabolic processes hence affecting the growth of the plants leading to low crop yield

Problem Statement and Justification

Agriculture remains the only major source of income in terms of employment and foreign exchange in Malawi. Climate variability has been significantly destructive and disruptive to crops growing communities threatening food security in the areas. Proposed research addresses one of the core challenges, as identified by the governments Malawi Growth and Development Strategy (MDGs) 2006-2011 of making Malawi food self-sufficient.

There has been a decline in maize production in Malawi over the past few years due to recurrent droughts, which have resulted in high variability in timing (onset), distribution and amount of rainfall and season length. Consequently, the past planting dates for maize in Malawi are out of phase and needs update (Kumwenda *et al*., 1998).

Crop modeling can help to predict productions under variable climate scenarios and this can help to develop strategies and technologies that can mitigate effects of climate variability. In Malawi, little research has been done on crop modeling, therefore DSSAT will be one of the quick decision making tool in this research.

Materials and Methods

Site

The study focused on Chitedze Agriculture Research Station in Lilongwe District of Central Malawi. Chitedze Agriculture Research Station lies at $13^0$58'S and $33^0$58'S; and altitude of 1146m. Chitedze falls in the mid altitude areas with annual rainfall of 800mm-1200mm, well drained sandy loam soils classified as alfisols (Brown and Young, 1962).

Table 1: Agro ecological characteristics of Chitedze Agricultural Research Station, Lilongwe District

Characteristics	Value
Length of growing period (days)	150-165
Mean temperature during growing period(^{o}c)	20.0-22.5
Mean annual precipitation(mm)	800-1200
Mean number of dry months	7-8
Mean annual temperature(^{o}c)	20.0-22.5
Mean minimum temperature of coolest month(^{o}c)	10.0-12.5
Plant-extractable soil Water(mm)	27.4
Available N, average of two samples(kg/ha)	60.0
Altitude	1146m
Soil class	CSA-Humid Sub Tropical Class from koeppen Map in DSSAT model software

(Source: Application of a maize crop simulation model in the central Region of Malawi. (Thornton *et al.*, 1995).

Data collection

Secondary data were collected on climate, cropping systems and soil characteristics

Cropping systems and soil characteristics data

Secondary data on maize cropping systems and soil characteristics were reviewed from literature. The sources of information included Chitedze Agriculture Research Station, libraries (Bunda College and Chitedze Agriculture research Station), ICRISAT, Ministry of Agriculture and Food Security, selected Extension Planning Areas (EPAs) in Lilongwe; Lilongwe Agriculture Development Division, Lilongwe District Agricultural Office, and scholarly articles.

Climate data

Climate data for the previous 30 years were accessed from the Department of Climate Change and Meteorology Services of Malawi. Solar radiation, daily rainfall, relative humidity, sunshine hours, minimum and maximum daily temperatures data were accessed. This data was complemented by data from NASA web portal.

Data analysis

Descriptive and Inferential Statistics

Estimate of cumulative annual totals of rainfall, temperatures, and yield data of the crops was plotted against their corresponding years. Time series, correlation and multiple regression was used to analyze the relationship existing between the variables. The Index of Agreement (d-stat), coefficient of determination (R^2) were calculated to find out the direct relationship existing between the simulated and the observed maize yields of the past 12 years of cropping seasons.

Method of manipulation of the data set

The data for 12 years starting from 1996/1997 to 2007/2008 growing season was used to plot graphs. The yield data was in form of production and these were converted into tonnes per hectare by dividing total production of that season by area. The observed yields were plotted against the seasonal rainfall to check the consistency of the data and the correlation between the yield and seasonal rainfall.

Rainfall and yield of maize

The daily rainfall data starting from 1997/98 to 2007/08 cropping season was analyzed. That is total wet days, total dry days, seasonal rainfall, annual rainfall were calculated using the daily rainfall data for Chitedze Agriculture Research Station. The methodology used in this study was adapted from Genesis *et al* (2010).

The total dry and wet days hence were derived within the growing season (taking advantage of the seasonal period that is considering the onset of rainfall and cessation of rainfall). Dry days is amount of rainfall less than 1mm, whilst wet days the rainfall amount is 1mm or greater than 1 mm of rainfall received daily.

DSSAT program

DSSAT-CERES maize model was used to run the simulations for maize at Chitedze under specific climatic conditions, soil characteristics, cropping systems and management practices. The Decision Support System for Agro-technology Transfer (DSSAT) Version 4.5 is a software application program that comprises crop simulation models for over 28 crops. Data base management programs for soil, weather, and crop management and experimental data, utilities and application programs support DSSAT. The crop simulation models simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics (Hoogenboom et al 2003).

Input files creation

Weather file

The weather data was entered in excel sheet that includes rainfall, solar radiation, wind speed, sunshine hours, relative humidity. Then DSSAT utility weatherman was used to import the weather data for Chitedze. The DSSAT has the capability to recalculate the missing values once commanded.

Soil file

The soil file was created using the physical and chemical soil data of the study site. Firstly, the soil data was manually added into the soils database. DSSAT recalculated the missing values once commanded.

Experiment file

Creation of experiment file involved input of crop management data into the DSSAT model. For missing values, you look at parameters of a crop in the DSSAT that is similar to the variety of focus in the study. Running of the model was successfully done using the weather data, soils file and the experiment that was created using the crop management data

Results and Discussion

Historical rainfall patterns effects on yields of maize

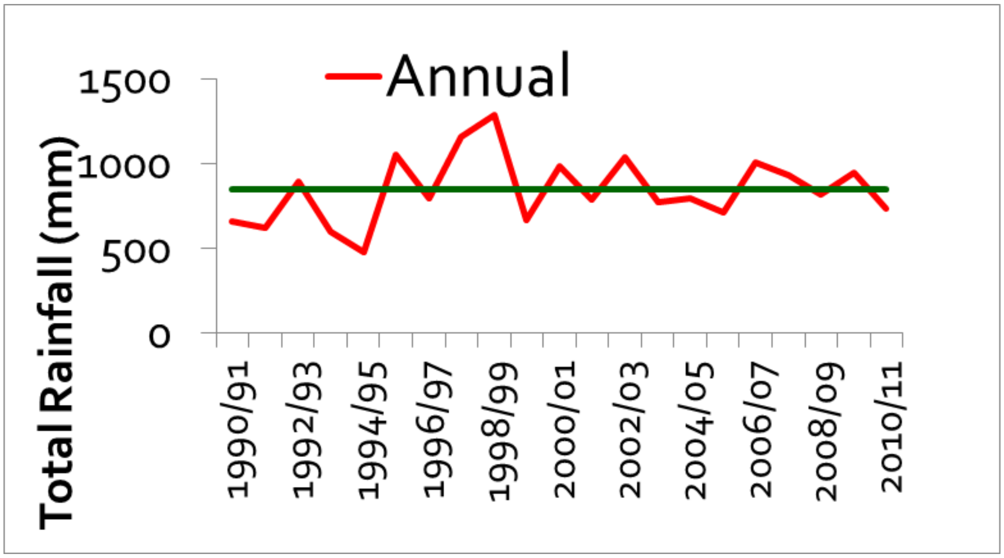

Figure 1: Seasonal rainfall variation from 90/91 to 10/11 cropping seasons at Chitedze Research Station

Figure 1 shows that rainfall at Chitedze Research Station is highly variable and is the most important variable affecting the yield. Maize requires a well-distributed, considerable amount of rainfall over an appropriate numbers of days during its growing season for optimum yield, with largest rainfall of about 1285.1mm in the year 1998/1999 cropping season.

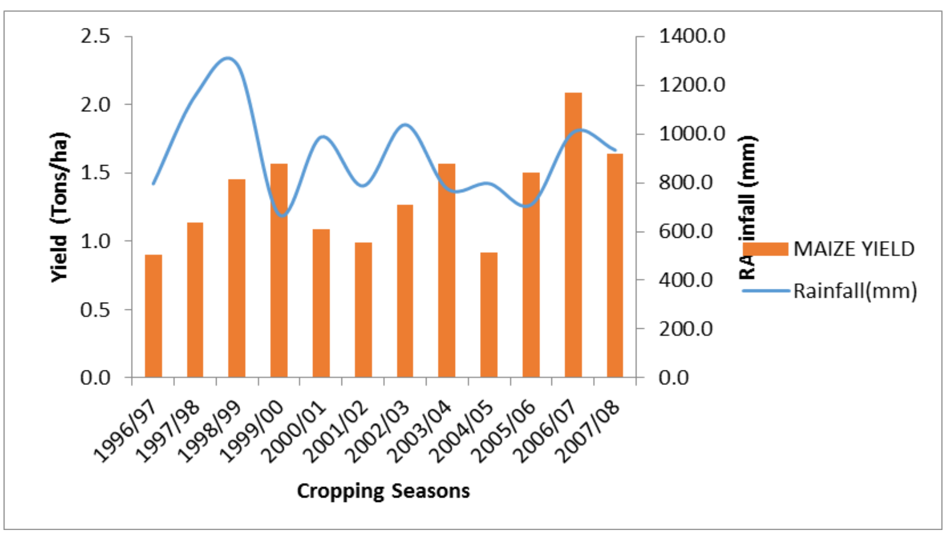

Figure 2: Maize grain yield and total annual rainfall for Chitedze Research Station from 1996/97 to 2007/08 cropping seasons

Figure 2 shows the trend of grain yield in Lilongwe District over 12 years from 1996/97 cropping season. Starting from 1996 there was an increase in yield but in 2000/2001, the yields decreased. The decrease in yield in 2000/01 coincides with the period Malawi experienced dry spells and a reduction in total annual rainfall. The results in Figure 2 shows that in 2000/2001 season and 2006/2007 period the rainfall amount was equal but yields were high in 2006/2007 season and this could be due to introduction of farm input subsidy programme (FISP). The FISP programme solved the input problems like scarcity of seed and fertilizer which led people have sources of inputs (MOAFs 2006) for maize production. Cicek *et al* (2005) found out that of all the climatic parameters affecting crop production and yield, moisture is the most important parameter. Moisture is primarily gotten from rainfall that in the tropics usually cyclic and highly dependable.

Table 2: Total dry days, total wet days, annual rainfall (mm) seasonal rainfall amount (mm), rainfall onset date, rainfall cessation date, observed maize yield (kg/ha) and the length of the growing season

Cropping season	Total wet days	Total dry days	Length of growing season (days)	Annual rainfall (mm)	Seasonal rainfall (mm)	Rainfall onset day	Rainfall cessation day	Observed yield (kg/ha)
1996/1997	65	53	118	845	634	11 Dec	8 April	1100
1997/1998	70	63	133	1157	879	8 Dec	20 Mar	1100
1998/1999	64	37	101	1285	912	22 Dec	2 Apr	1500
1999/2000	56	53	109	669	498	22 Dec	10 Apr	1600
2000/2001	29	90	119	988	424	21Dec	21 Apr	900
2001/2002	34	59	93	787	577	21Dec	23 Apr	1000
2002/2003	48	59	107	1038	768.5	10 Dec	27 Apr	1300
2003/2004	53	43	96	776	713	10Dec	15 Mar	1600
2004/2005	47	47	94	845	680	8Dec	12 Mar	900
2005/2006	53	85	138	710	689	25Nov	12 Apr	1500
2006/2007	60	71	131	1007	927	27Nov	7 April	2100
2007/2008	79	23	102	933	873	7 Dec	19Mar	1600

Table 2 shows results of annual and seasonal rainfall distribution, number of wet and dry days, onset and cessation of rainfall, length of growing season and observed maize yields from 1996/97-2008/08 seasons. There is variation in weather variables as observed in the number of wet days (20-79), dry days (23-90), and length of growing period (93-118). 2006/2007 cropping season optimum maize grain yield were obtained because of less number of dry days.

The trend in table 2 shows that high yields are highly correlated to high values of wet days, whilst those cropping seasons having high dry days are associated with low yields. The results are also supported by high seasonal rainfall amounts of 927mm which is within the recommended levels for cropping season 2006/2007, according to Kumwenda (1998) between 800mm-1200mm hence high yields obtained, whilst in the cropping season 2000/2001 the seasonal rainfall amount was 424mm which is very low and below the recommended rainfall amount

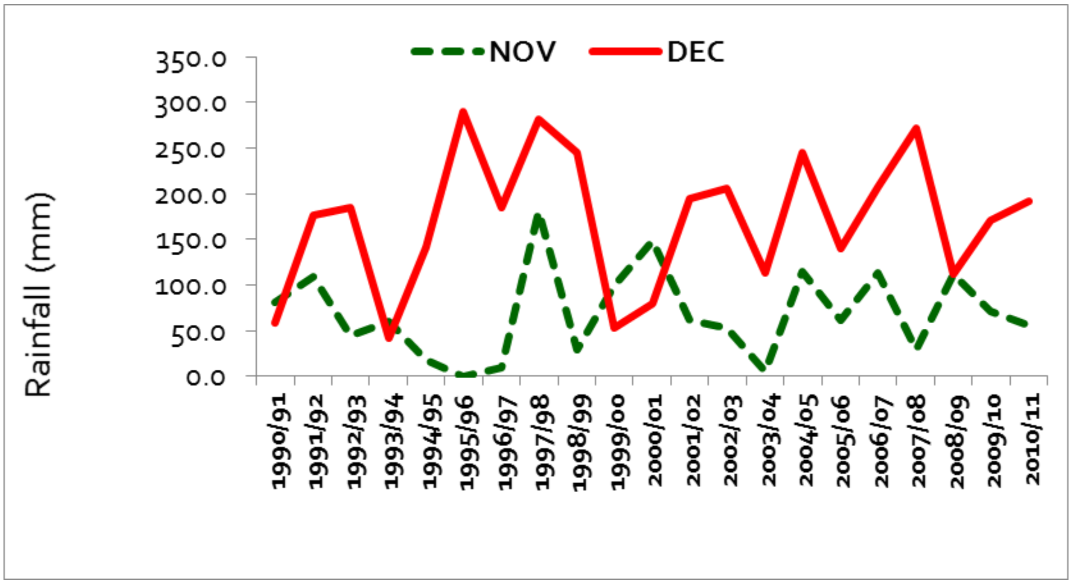

Figure 3: Monthly rainfall (mm) for November and December for Chitedze Research Station

Figure 3 clearly shows that December month, rainfall reached its peak than November. Rain days have the greatest influence on maize yield in the study area. This means that despite the fact that maize plant requires a considerable amount of rainfall for effective growth and yield, it is still highly sensitive to excessive rainfall and continuous daily rainfall pattern typical of the tropics during raining season

Table 3: Results on number of wet and dry days for the month of November, December and January from 96/97 to 07/08 cropping seasons

Month	Mean		Standard deviation		Total days	
	Wet days	Dry days	Wet days	Dry days	Wet days	Dry days
November	5	25	4	4	65	325
December	27	16	3	3	189	214
January	18	13	4	4	235	168

Table 3 shows results on number of wet and dry days. December month received equitable amount of rainfall supporting the growth and development of maize plant because it had the largest mean wet days of 27±3. This shows that maize planted in November and January suffers a moisture deficient and excessive wet condition respectively that affects maize yields. In January, the number of wet days were excessive than dry days, whilst November month the wet days were just too little (5±4) compared to dry days (25±4) which implies that if maize is planted this month, seed emergence and establishment is affected by the dry spells and this has a negative implication on maize growth and yield generally that affects maize growth. For the month of December, the wet days were at recommended level (27±3) versus dry days (16±3) which is not very bad hence supporting maize growth. December could be the best time to plant maize as throughout there is an equitable amount of rainfall received in a number of days hence supporting the vegetative, flowering stages of the plant leading to efficient biomass partitioning hence high yields other than the January and December month.

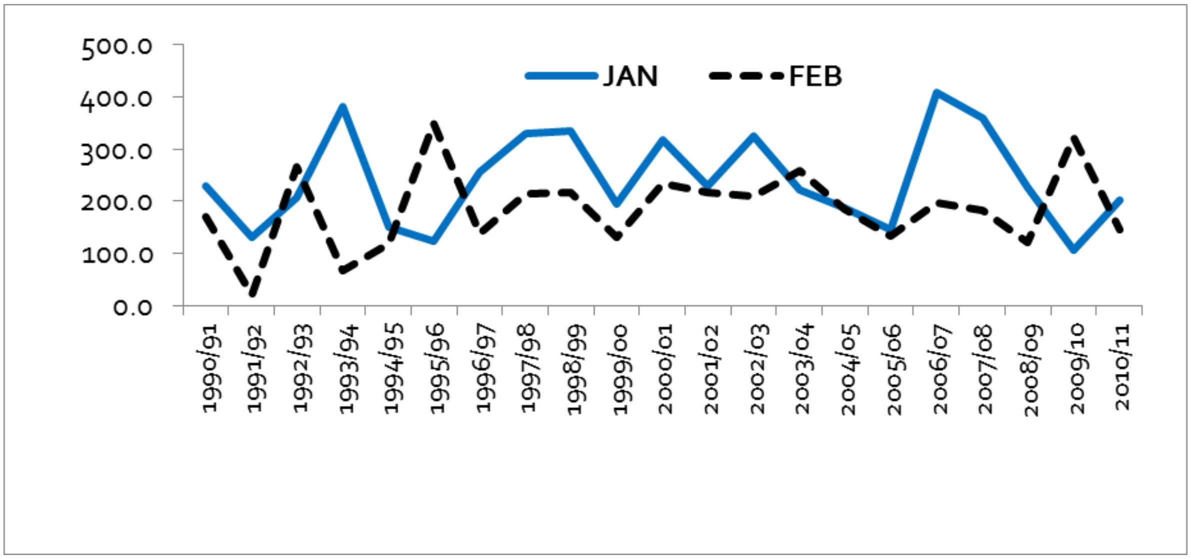

Figure 4: Monthly rainfall, January, February for Chitedze

Figure 3 and 4 shows the trend in rainfall patterns for the months where most farmers' plant maize crops during the period of December, January and those farmers who plant late, around January and February in Lilongwe District. Overall, the trends indicate variability of rainfall patterns over a 12 year period and this can affect planting dates hence all these changes in planting dates and months are partly due to continuous shifting of the rainfall patterns with later rainy onset in most of the areas in the country and earlier cessation in all areas.

In general, climate models have shown that in Malawi the trend in rainfall patterns will continue into the future (Malawi Vulnerability Assessment, 2013). With the average monthly rainfall expected to decrease during the months of December and January and increase during the months of February, March and April. Overall, the rain day frequency is expected to decrease slightly while dry periods are expected to increase. Therefore, since different areas are affected by rainfall variability at different levels, hence the research should be conducted in a number of districts to find out how the yields respond to different rainfall amounts.

DSSAT application to simulate yields of maize

The cropping management, weatherman and soils files were created to help in running the model. The main aim of using the DSSAT model was to check the model efficiency in simulating the maize yields for Chitedze Research Station. The simulation for this run was on 1st November of every cropping season, but the rest of the scenarios the simulation started 10 days before planting, so that the model could simulate and be able to model the available moisture in the soil.

Fig 5 shows results by control simulation. There is a positive correlation (R^2=0.788) between the simulated and the observed maize yield which signifies that the DSSAT model was able to predict the yield of the historical data set. The simulated yields somehow substantially over predicted observed yields (mean=1429 kg/ha vs. 1350 kg/ha).

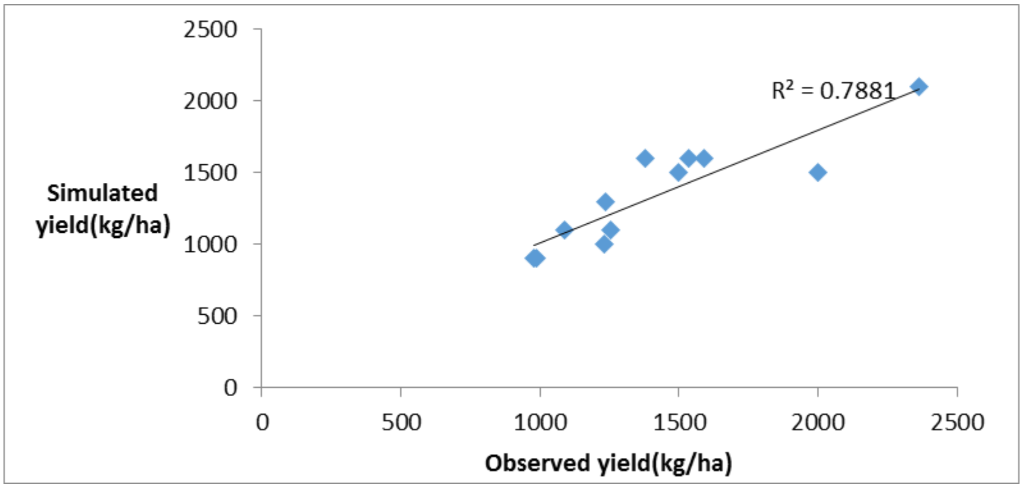

Figure 5: Simulated maize grain yields against observed maize grain yields

Assessment of the effect of time of planting on maize yield in relation to climate variability

This objective aims at applying different management scenarios to the model to check the effect on yield of maize. In this study, the effect of planting dates on the yield of maize was modelled. The planting dates were Early November (15 day of the month), late November planting (30th day), early December planting(15 December), late December planting(30 December), and Early January(15th day), and late January (30th day). The assumption was that all agronomic parameters were kept constant for example soil fertility management, weeding only changing the planting dates. Rainfall being received, its impact on plant growth and development can be quantified easily compared to other climatic parameters like solar radiation, hence this study was focusing on the rainfall variability and how changing the planting dates affected the yield of the maize.

Table 4: Simulated and observed maize grain yield (kg/ha) at different planting dates

Planting dates	Mean observed (kg/ha)	Mean simulated (kg/ha)	Mean difference (kg/ha)	R square (R^2)	RMSE (kg/ha)	d stat (Index of Agreement)
Standard run	1350	1429	78.93	0.788	198	0.888
15-Jan	1350	901	-448.84	0.525	519	0.534
30-Jan	1350	848	-501.58	0.479	491	0.463
15-Nov	1350	1102	-247.94	0.526	520	0.563
30-Nov	1350	1166	-183.64	0.678	292	0.663
15-Dec	1350	1250	-99.61	0.77	221	0.861
30-Dec	1350	1207	143.41	0.751	314	0.763

Table 4 shows that planting maize at Chitedze in early (15th December) produces high yield of both simulated and observed maize yield. The highest mean simulated yields are obtained using the DSSAT model on this date other than the standard run which has coefficient of determination (R^2) of 0.788; RMSE is 197.90 and d-stat which is the index of agreement being 0.888 which signifies the capability of the DSSAT model to simulate maize yield at Chitedze, as the simulated and the observed maize yield are highly correlated.

The mean simulated yield for early December being 1250.39 kg/ha other than to the ideal situation. Planting in early December has many advantages because during this period the rain reaches its peak. From the results, the planting date of early December has got a coefficient of determination (R^2) of about 0.770 which shows that the simulated maize yield and the observed yield are highly correlated implying the capability of the model or the model performed very well followed by 30 December then 30 November, 15 November, 15 January, 30 January having the R^2 being 0.751, 0.678, 0.526, 0,525 and 0.479 respectively. The results show that planting on 30th January tends to reduce the yields. Planting on 15 December, from the table 3 it can be seen that the index of agreement is 0.861 which is very close to 1, it means it was a good simulation (Kihara *et al .,* 2010).

The root mean square of Error being 220.689 kg/ha which is small compared to the rest of the dates hence it signifies that little error of about 220.689 kg/ha of grain loss can occur if planted on 15 December whilst about 520.087kg/ha of maize could be lost when you plant your maize early November, that is you expect more grain loss or errors when you plant maize on 15 November, 30 January and 15 January because they have greater RMSE values being 520.09kg/ha, 491 kg/ha and 518.95 kg/ha respectively compared to 15 December because during the end January most of the soils have reached the field capacity already and also since during the end January most of the times the wet days are too much compared to dry days hence plant growth is inhibited. The concentration of rain days during rainy season has a great influence on maize yield annually such that the higher and less evenly distributed the number of rain days, the lower the maize yield. This is in agreement to Cicek *et al* (2005) who found out that rainfall, sunshine, temperature, evaporation, are closely interrelated in their influence on maize . However, of all the climatic parameters affecting crop production and yield, moisture is the most important parameter. Moisture is primarily gotten from rainfall that in the tropics is cyclic and dependable. During period of heavy rain, the interception of light from the sun is not absorbed to the maximum point hence some physiological and biological processes are affected which affects the development and growth of maize crop for example canopy cover which when not sufficient tend to reduce the dry matter.

In terms of early November, generally the dry days were greater than wet days hence this affects the water uptake by the plants affecting the yield/dry matter accumulation at the end of the season. Early November here in Malawi, rainfall is not yet at its peak, hence planting around November could be the waste of grain as germination is also affected. Despite the fact that maize plant requires a considerable amount of rainfall for effective growth and yield, it is still highly sensitive to excessive rainfall and continuous daily rainfall pattern typical of the tropics during raining season.

The mean difference of simulated and observed yield is small, that is the observed yield deviate by about 99.61 kg/ha which is a small difference compared to the other five dates which have a larger value, which signifies how close the simulated yield is to the observed yield which signifies how good the DSSAT model is in simulating. Planting around early December is in agreement with the fewer dry days as shown in figure 9 experienced at Chitedze, meaning the soil had good soil moisture condition.

The results show that planting maize early December increase maize yields with low reduction (9.59%). Overall, the results show that planting early December (15th December) and late December (30th December) there is no much difference in terms of yield. Smallholder farmers if they plant on early and late December optimal grain yields are produced.

The results from this study recommend smallholder farmers to plant in December other than November and January month. January and November month are associated with high grain losses of 15.98% and 35.2 % respectively. It is the role of scientists to mainstream good management practices like encouraging smallholder farmers to plant early to make full use of the rainfall that is equitably distributed during the December month.

Reduction %= (Average observed yield-Average simulated yield)/Observed yield*100

Table 5: Reduction of maize yield planted in December, November and January

MONTH	TOTAL SIMULATED YIELD (kg/ha)	Average simulated yield (kg/ha)	Average observed yield (kg/ha)	Yield reduction (%)
DECEMBER	2456.98	1228.49	1350	9.59
NOVEMBER	2268.42	1134.21	1350	15.98
JANUARY	1749.58	874.79	1350	35.2

Conclusion

DSSAT has the capability to simulate crop yield. However, there is requirement to downscale at farm level. It was observed that the model simulated some high yields than observed from the field experiments. Generally, this could be so because the model itself can be off by one day as it does not clearly indicate when during the day the rainfall occurred and at what time the measurements of rainfall were taken. There was no consistent relationship between the trends in the observed annual rainfall and the observed yield. Rainfall distribution within the growing season affects the maize yield responses. The critical rainfall variables affecting the maze yield were seasonal rainfall, total wet days and total dry days.

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Appendix

Table 6: Soil moisture % characteristics data for Chitedze Research Station

Soil depth	Early season		Mid season	
0-20	11.1	13.6	29.1	24.1
20-40	25.0	16.3	29.1	22.2
40-60	25.0	22.0	26.4	47.2
60-80	25.0	28.2	24.8	26.5
80-100	42.9	16.3	28.2	7.3
100-120	25.0	16.3	29.9	27.1
0-20	16.3	13.6	28.4	32.1
20-40	25.0	22.0	25.5	9.2
40-60	25.0	19.0	26.1	14.3
60-80	25.0	22.0	27.7	35.2
80-100	25.0	28.2	26.6	35.1
100-120	25.0	22.0	26.5	12.3
0-20	11.1	16.3	26.4	23.6
20-40	25.0	22.0	22.6	29.7
40-60	11.1	22.0	24.3	53.6
60-80	25.0	22.0	24.3	23.9
80-100	25.0	28.2	23.3	13.7
100-120	25.0	31.6	23.0	23.2
0-20	25.0	28.2	24.4	22.8
20-40	11.1	22.0	19.7	24.8
40-60	25.0	28.2	26.1	43.6
60-80	25.0	28.2	24.1	22.0
80-100	25.0	28.2	26.0	22.8
100-120	25.0	28.2	24.7	23.8
0-20	11.1	22.0	15.1	24.5
20-40	11.1	19.0	17.4	28.3
40-60	25.0	19.0	17.9	24.1
60-80	25.0	22.0	17.3	23.2
80-100	25.0	28.2	16.8	22.5
100-120	25.0	35.1	17.2	24.6

Table 7: Soil moisture % at Chitedze Agricultural Research Station

	Soil moisture			
DEPTH(CM)	EARLY SEASON	CALIBRATED	MID SEASON	CALIBRATED
0-20	14.92	18.74	24.68	25.42
20-40	19.44	20.26	22.86	22.84
40-60	22.22	22.04	24.16	36.56
60-80	30	24.48	23.64	26.16
80-100	28.58	25.82	24.18	20.28
100-120	25	26.64	24.26	22.2

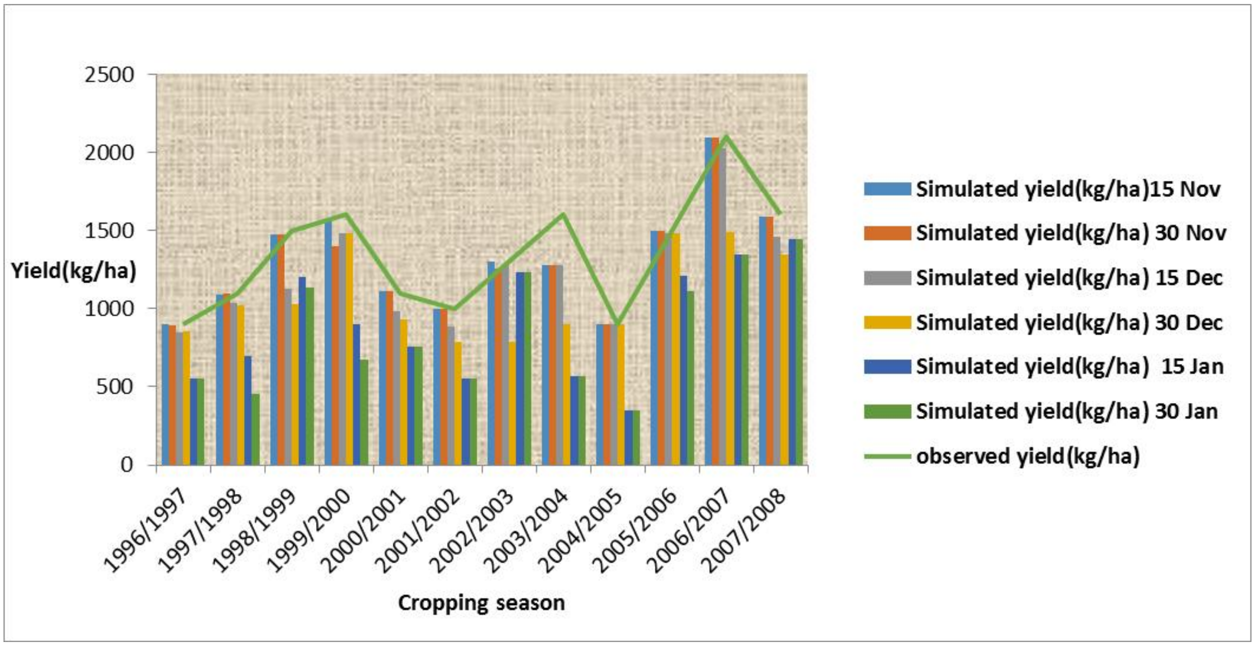

Figure 6: Simulated and observed maize grain yield for different planting dates against copping seasons.